Oscillations of Polymer Electrolyte Fuel Cells and the associated Water Management

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Outline

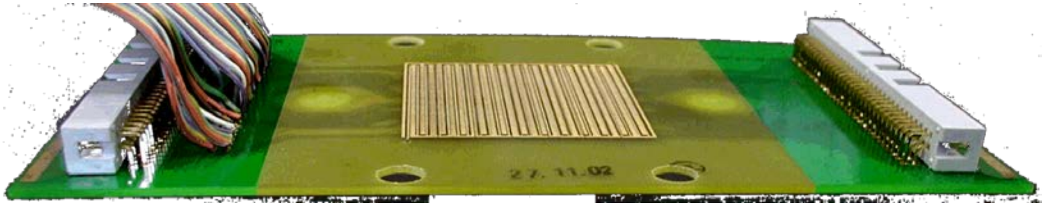
- Discussion of segmented cell designs for current density measurements
- Investigation of oscillatory fluctuations in PEFC
- Investigation of the triggering of the “ignition” transition

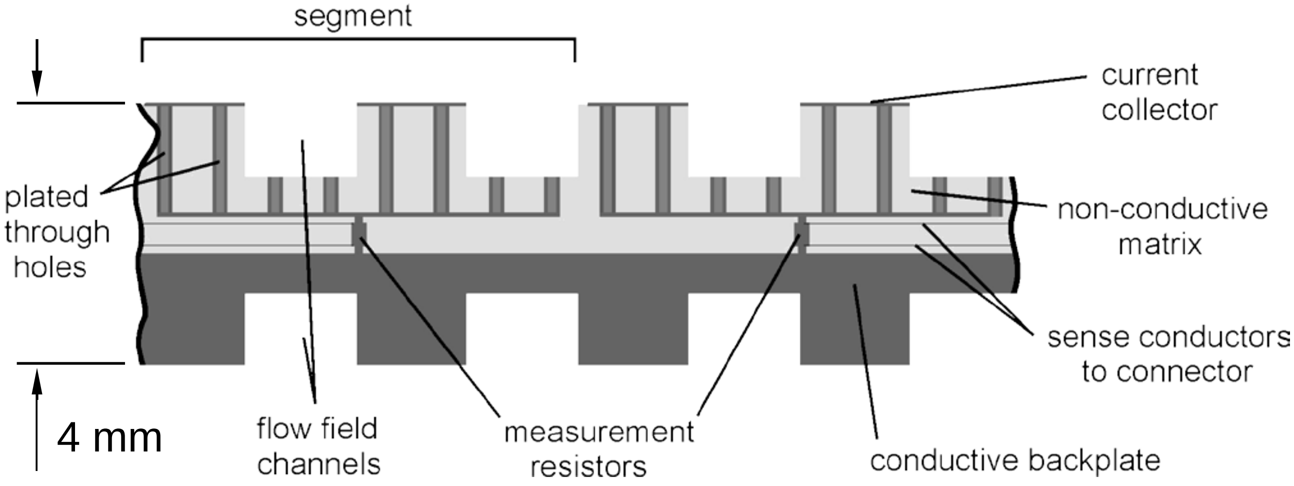
\- Earlier Work on Oscillations in PEFC:

J. R. Atkins, S. C. Savett, and S. E. Creager, Journal of Power Sources 128:201 (2004)
J. F. Moxley, S. Tulyani, and J. B. Benziger, Chemical Engineering Science 58:4705 (2003).
J. Benziger, E. Chia, J. F. Moxley, and I. G. Kevrekidis, Chemical Engineering Science 60:1743 (2005).
D. Garcia Sanchez, D. Diaz, R. Hiesgen, I. Wehl, and K.A. Friedrich, J. Electroanal. Chem. 649 (2010) 219-231.

Segmented Bipolar Plate for Current Density Distribution Measurements

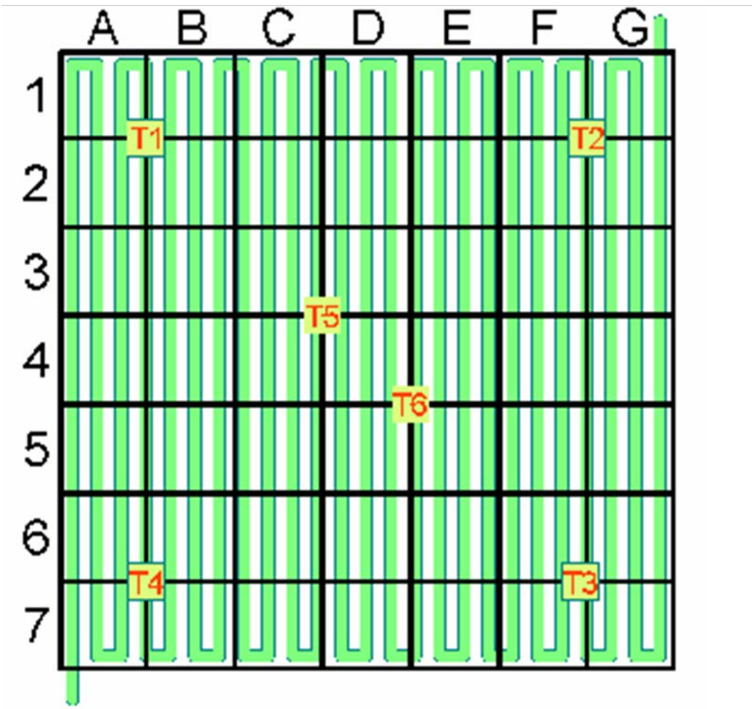
Current Density, Temperature, Impedance

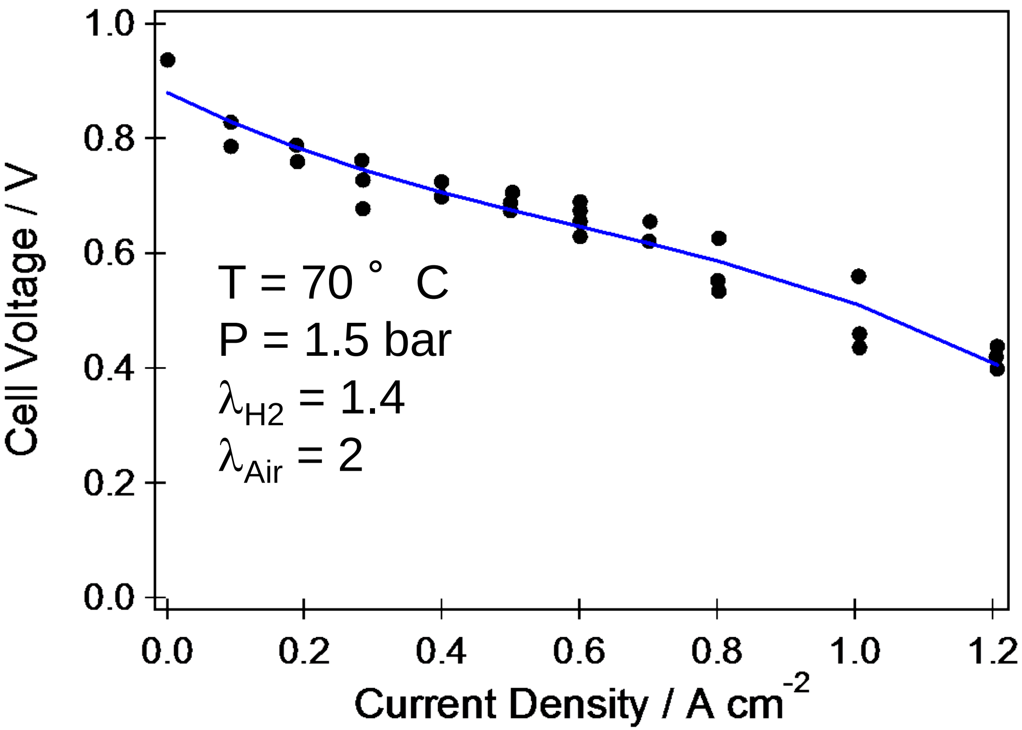




Flow Field and Ion Power MEA Performance

(A)



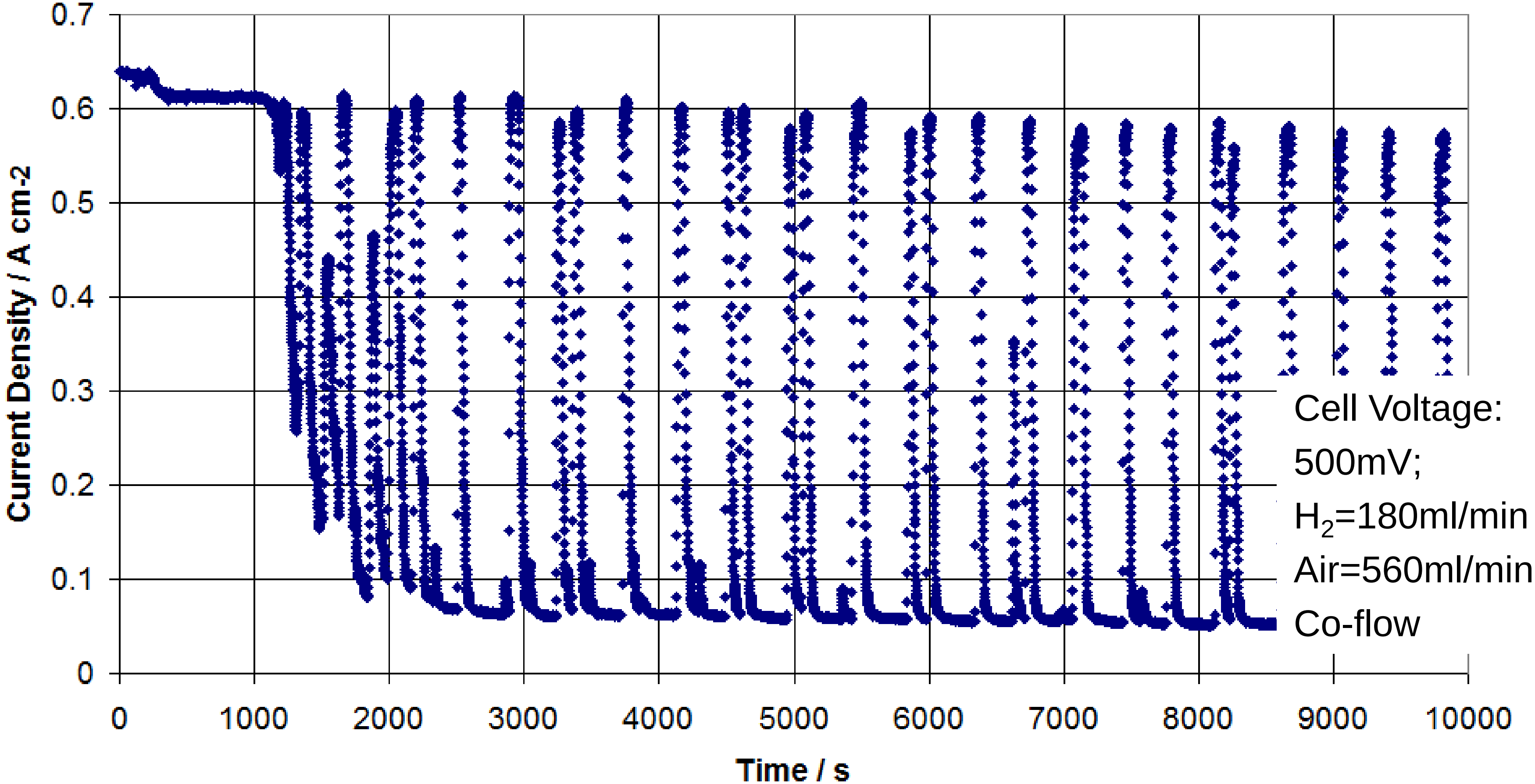


Configuration **A** (co-flow): Anode: input G1 output A7
Cathode: input G1 output A7

Configuration **B** (counter flow): Anode: input A1 output G7
Cathode: input G1 output A7

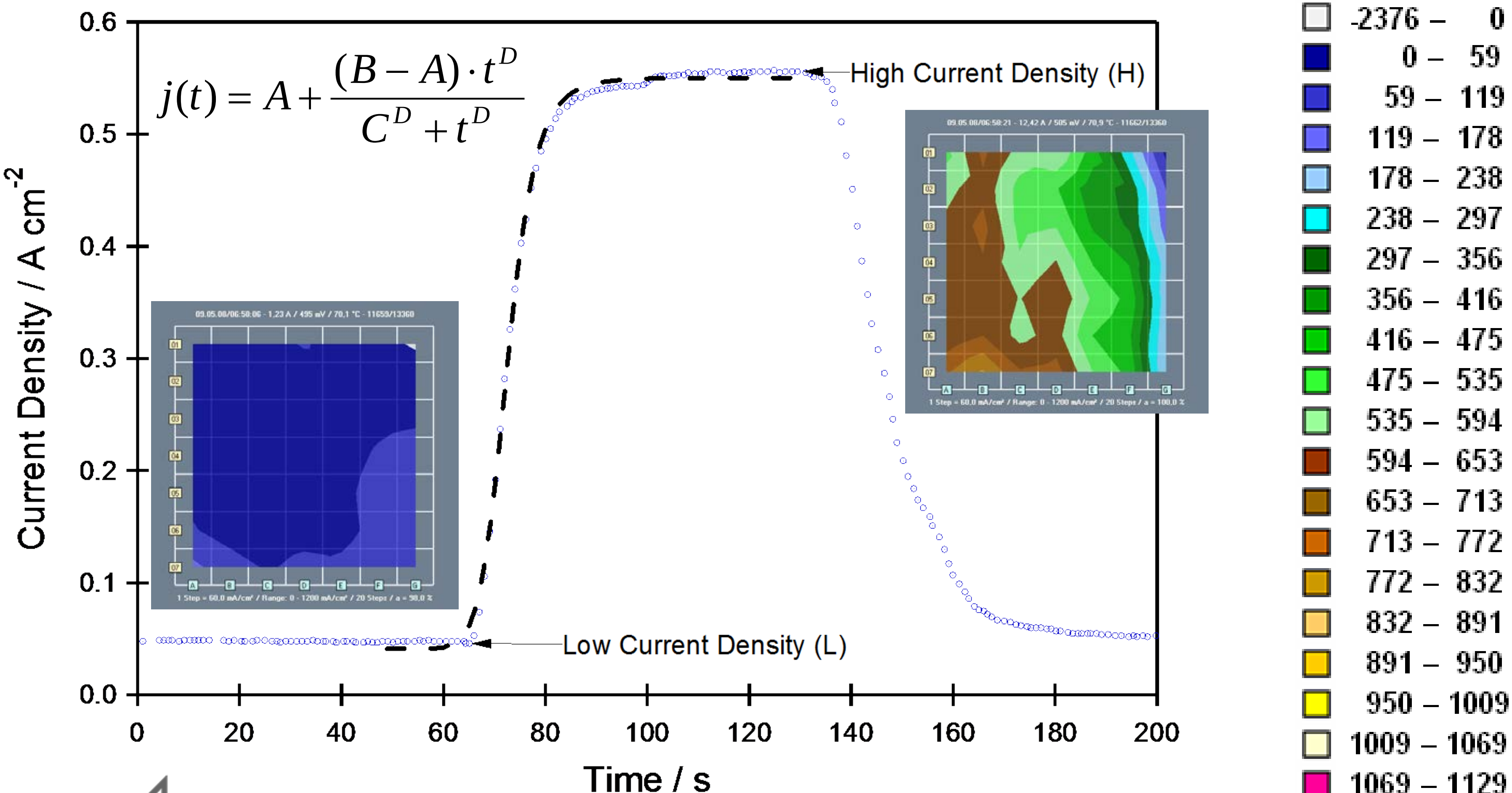
Oscillations of PEM fuel cells at low cathode humidification

Cathode with r.h.=0%, Anode with nominal r.h.=152% (condensing conditions)



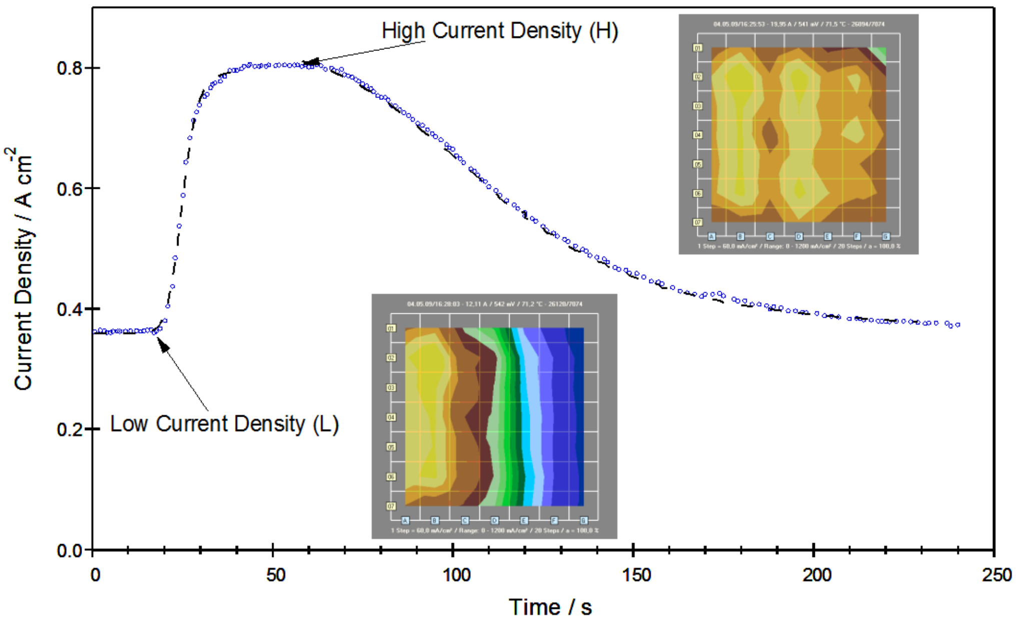
Current Density Distribution of Two Operation Points

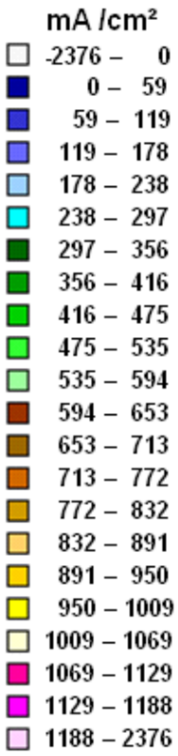
Co-Flow



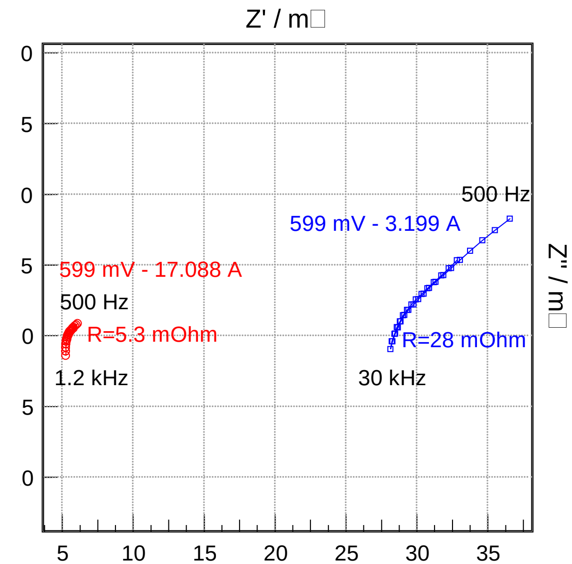
Current Density Distribution of Two Operation Points

Counter Flow



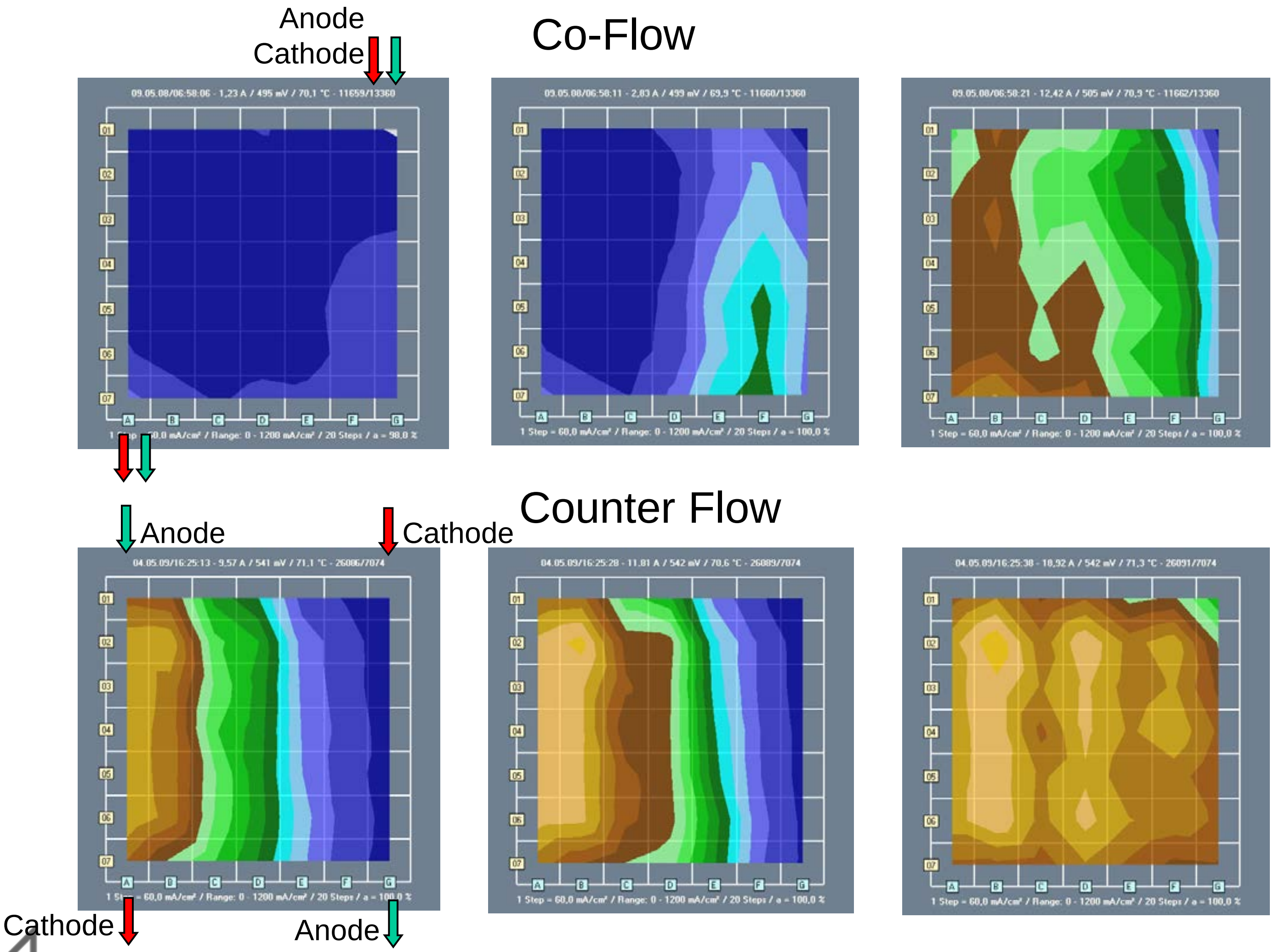


Impedance spectra of two operation points



- U_{cell}: 500mV, Cathode 660ml min^{-1}, Anode 200 ml min^{-1}; T_{cell}: 70° C; counter flow

Transition from Low to High Conductivity



Interpretation of the Oscillation Cycle

High ionic conductivity
Liquid water resevoir at anode
LVP

High electro-osmotic drag
and water permeation

Formation of liquid water

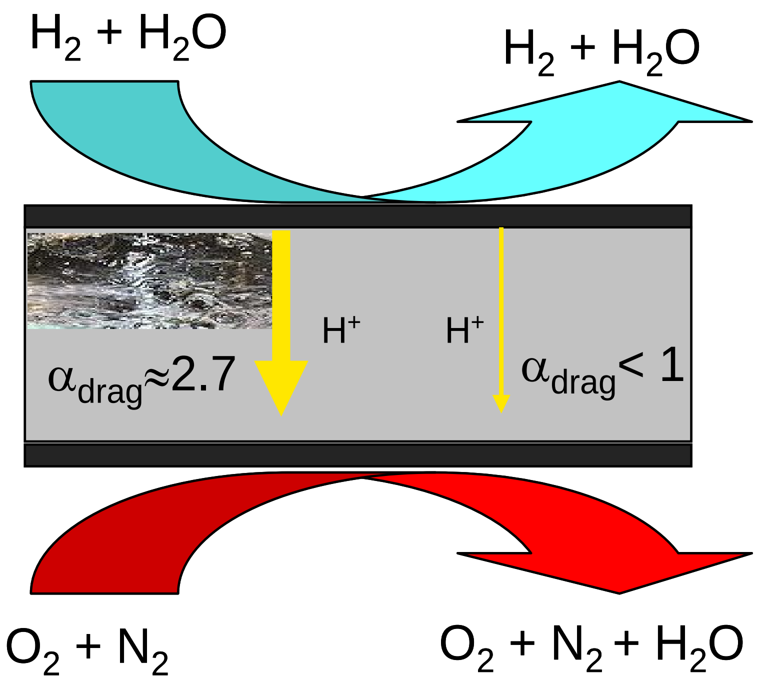
Rehydration Anode
~ 20 s

Dehydration anode

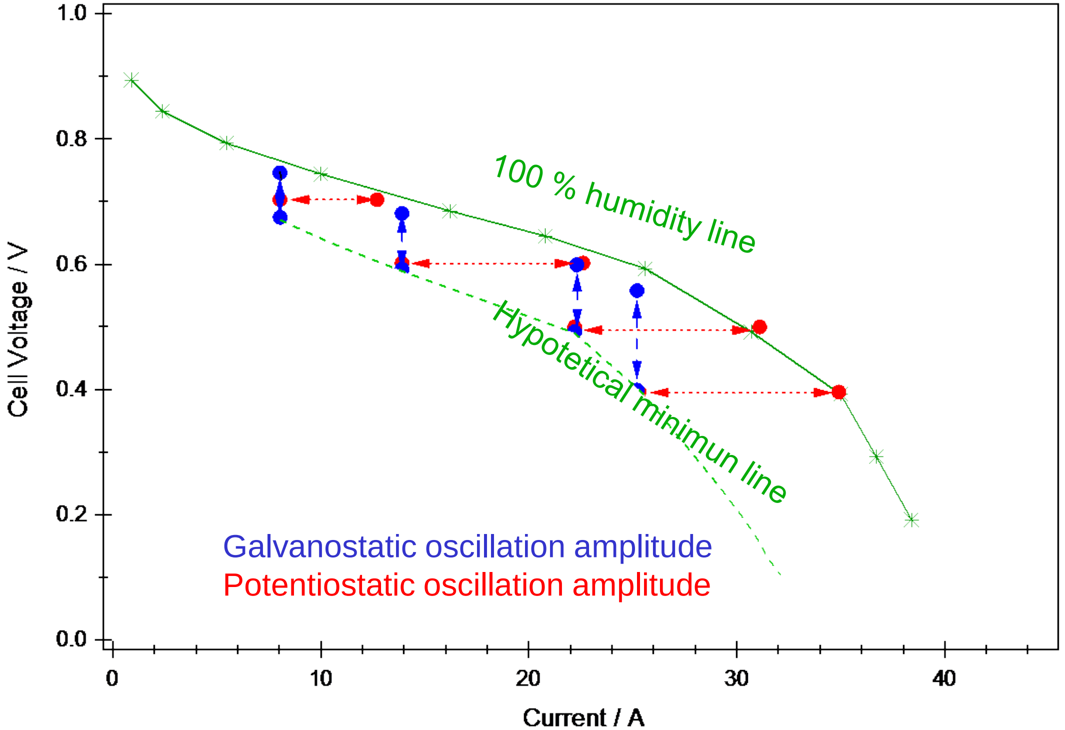
Anode without liquid water
High ionic resistance

Low electro-osmotic drag
and low water permeation

Low ionic conductivity
Anode without liquid water



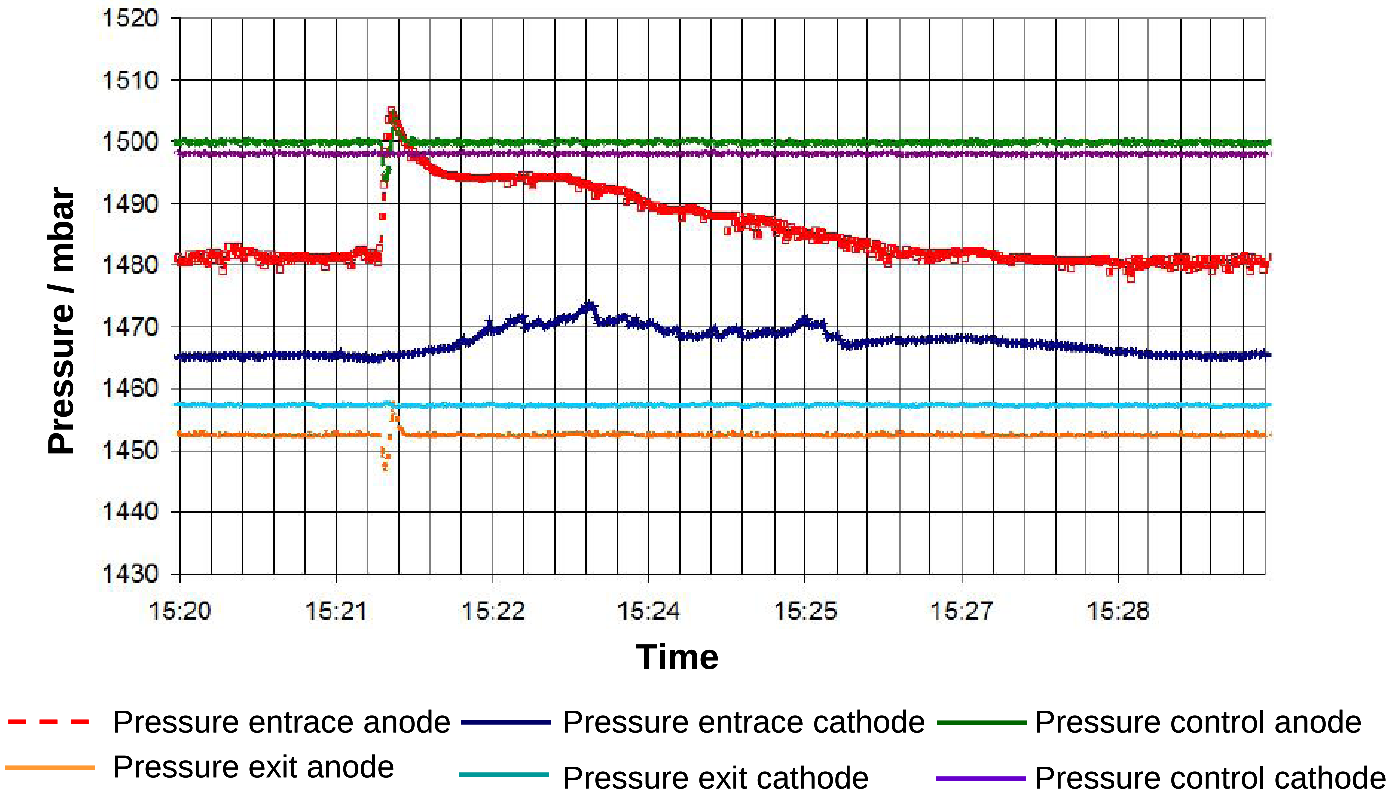
Oscillations are present under Potenstiostatic and Galvanostatic Operation Conditions



$RH_{Cathode}$= 0%
Stoichiometric ratio: 1.5 (H_2) and 2 (Air).
Reference (25 A)

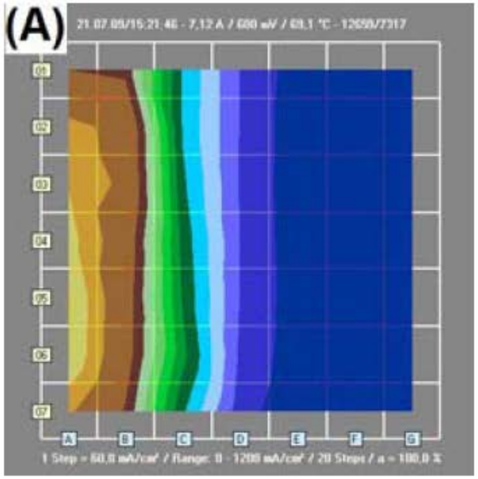
F_{H2}=261.5 cm^3/min
F_{Air}=830.9 cm^3/min

Investigation of the „Ignition“ Transition



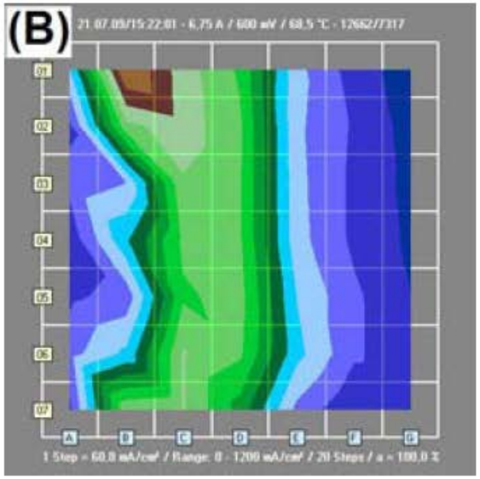
Observation of a pressure surge in the anode followed by a time delayed gradual pressure increase in the cathode compartment

Investigation of the „Ignition“ Transition / Current Density Distributions



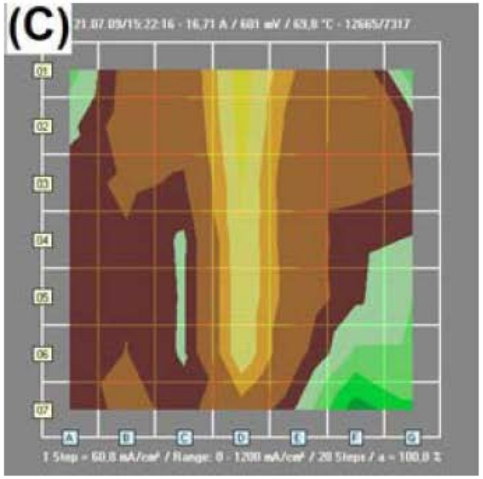
Low current level (L)

Current: 7.12 A



Before L to H transition

Current: 6.75 A



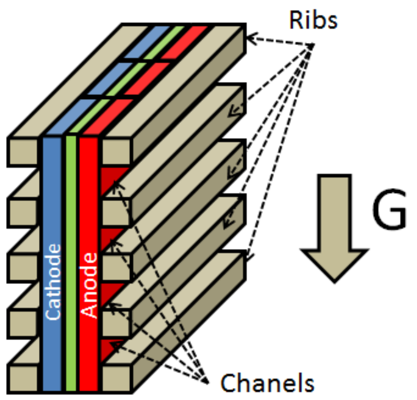
High current level (H)

Current: 16.71 A

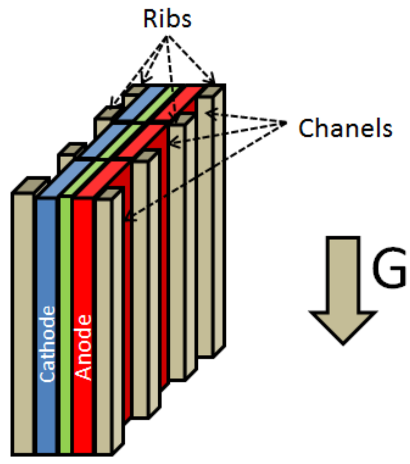
Blockage of chanel with liquid water?

Influence of the Orientation of the Cell

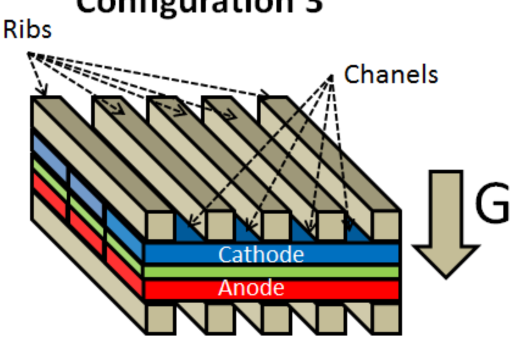
Configuration 1



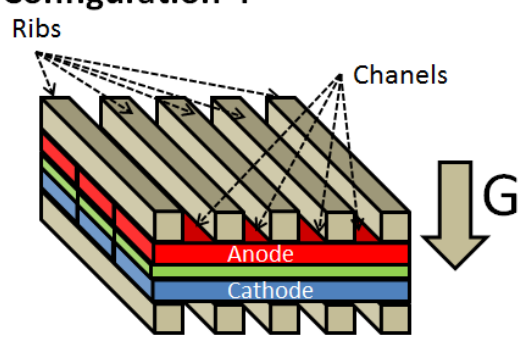
Configuration 2



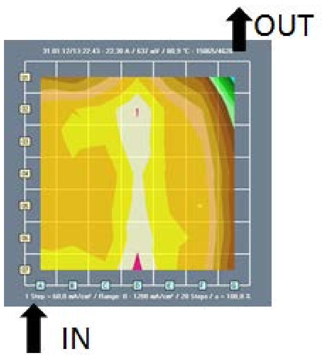
Configuration 3



Configuration 4



Co-flow



Experimental conditions:

Potentiostatic mode: 600mV

Flows:

Anode: 209ml/min

Cathode: 664ml/min

Bubbler Anode temperature: 80° C

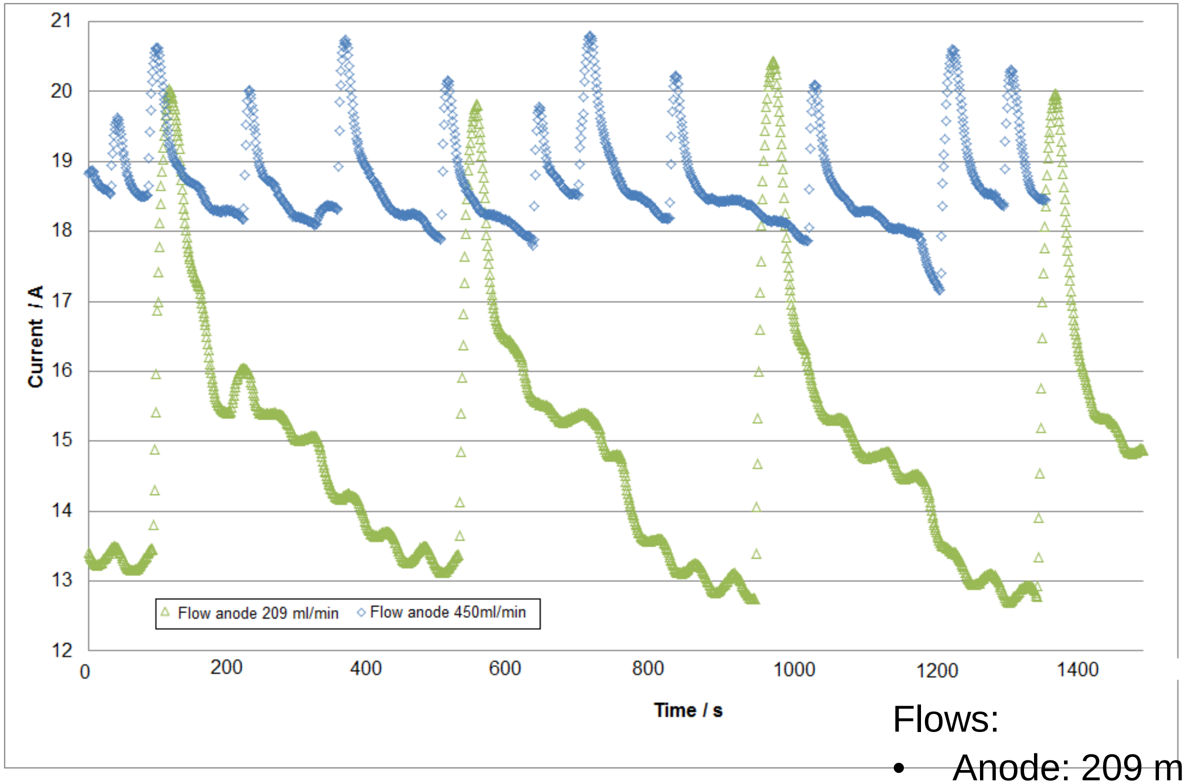
Cell temperatures : 70° C, 80° C, 85° C

Pressure: 1.5 bar

Relativity humidity cathode: 0%

Relativity humidity anode: variable

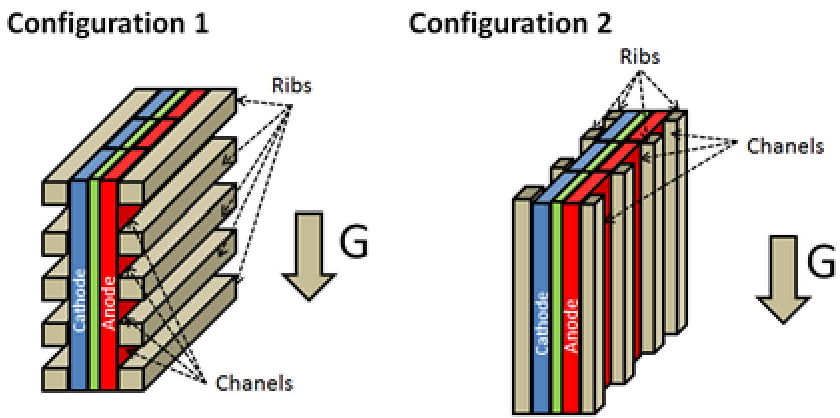
Oscillation Frequency dependent on the Anode Flow



Flows:

- Anode: 209 ml/min, 450 ml/min
- Cathode: 664 ml/min
- Relativity humidity cathode: 0%
- Relativity humidity anode: 100%

Comparison of Configuration 1 and 2

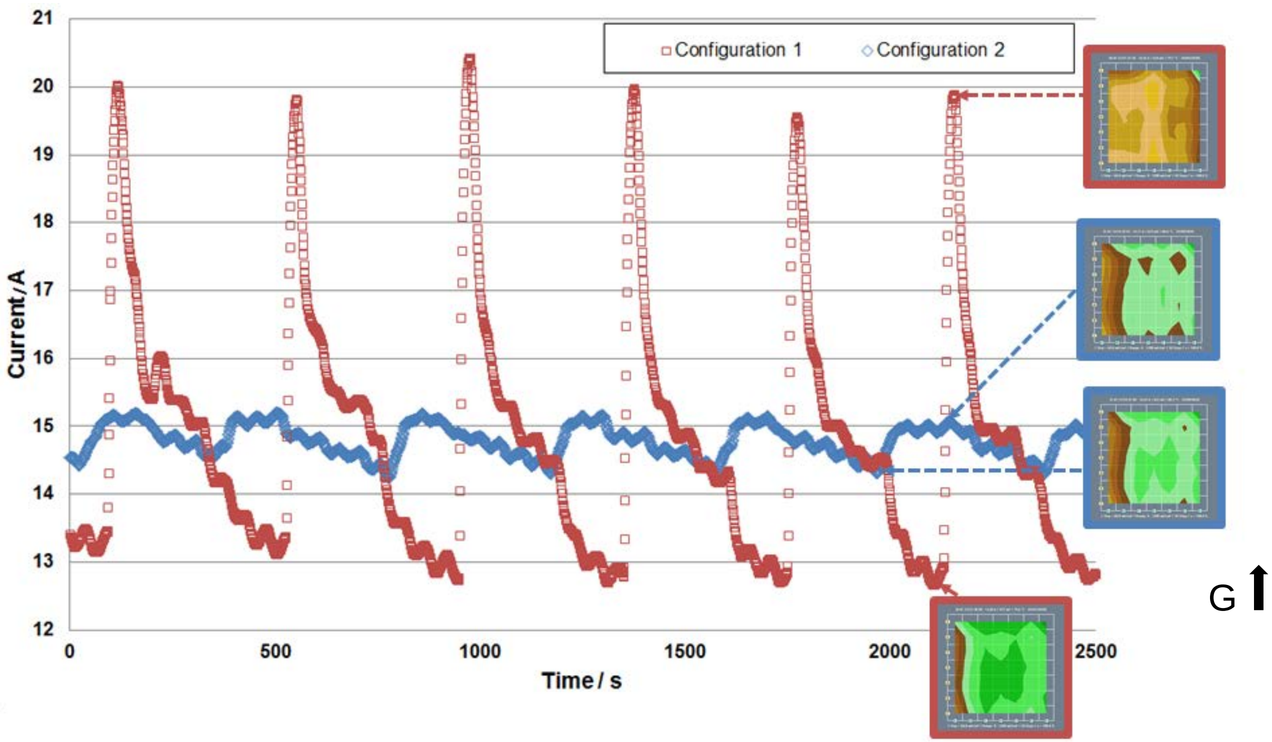


C1 C2

- Preferential formation of water drops observed in configuration 1 **(1)**
- Differences in the oscillatory behavior expected

(1) Zijie Lu, Cody Rath, Guangsheng Zhang, Satish G. Kandlikar. "Water management studies in PEM fuelcells, part IV: Effects of channel surface wettability, geometry and orientation on the two phase flow in parallel gas channels." *Journal of Hydrogen Energy* , 2011: 9864-9875.

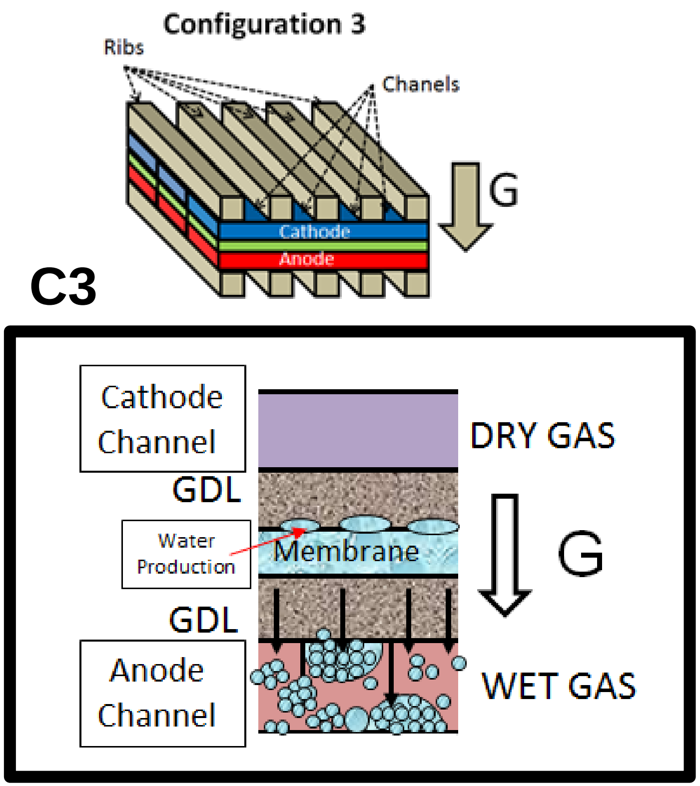
Comparison of Configuration 1 and 2

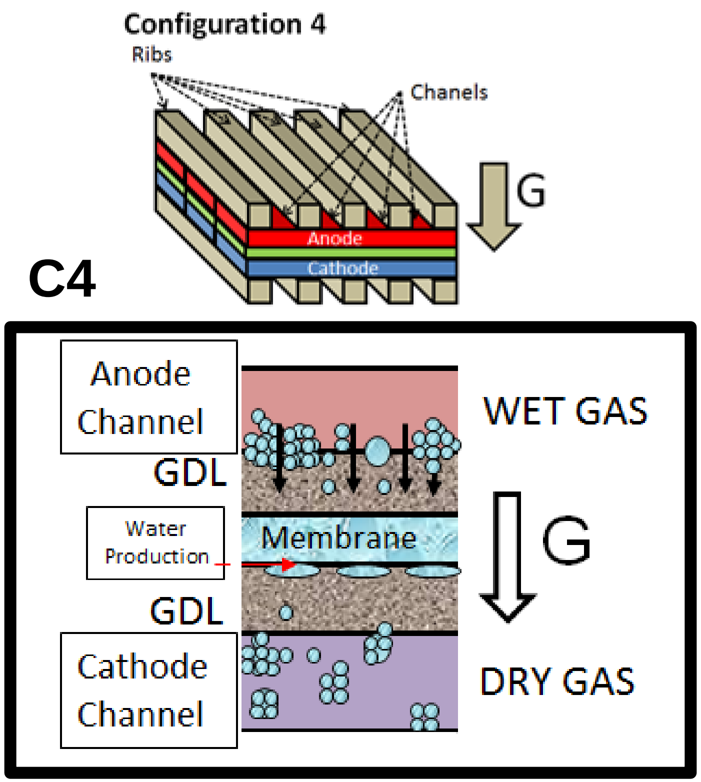


- Amplitude of oscillations in configuration 2 is diminished
- Frequency is unchanged
- Strong indication of importance of the „blocking“ effect

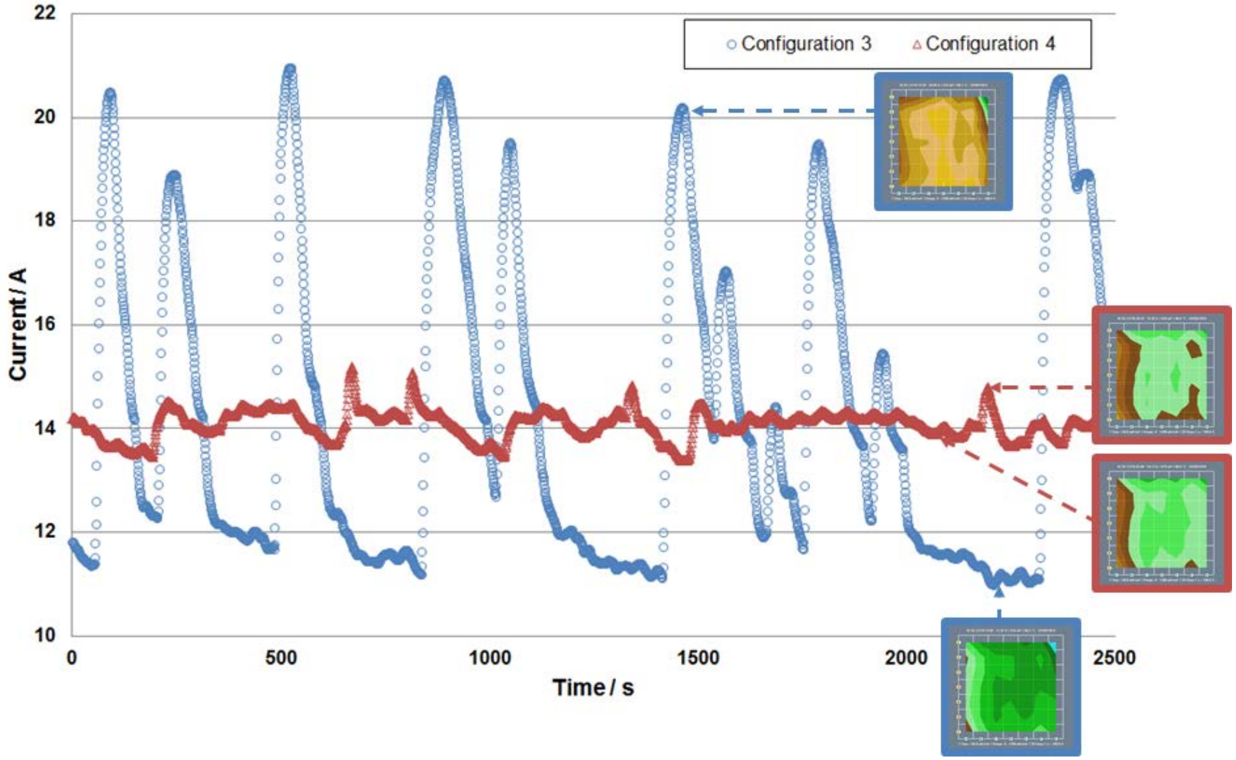
Comparison of Configuration 3 and 4

Influence of the orientation





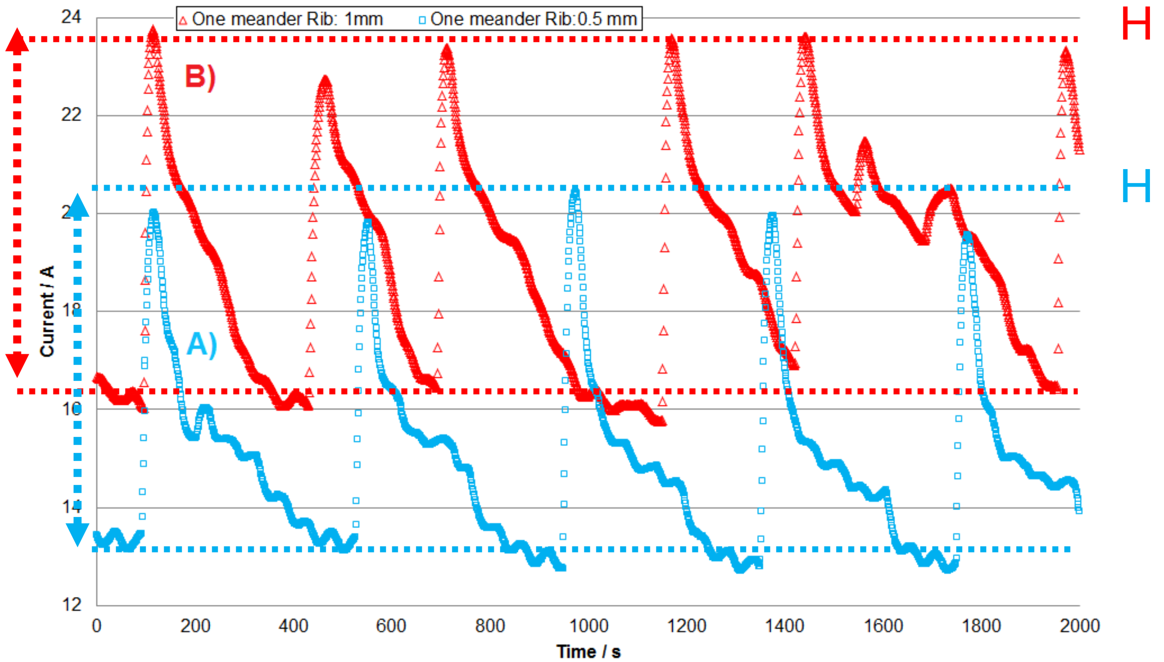
Comparison of Configuration 3 and 4



- Only for configuration 3 oscillations present
- Configuration 4 shows a stable intermediate performance

Other Design Parameters, e.g. Rib Thickness

Influence of the rib thickness in cathode side:
A) Rib thickness: 0.5 mm
B) Rib thickness: 1 mm

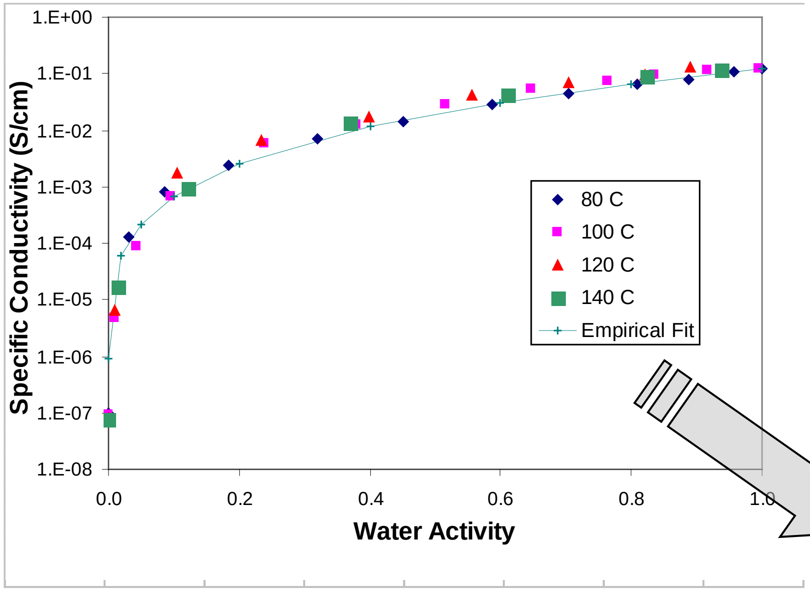


- Better response is expected with 1 mm rib which is observed.
- Both designs show the same amplitude and frequency
- No big differences in the phenomenology of the oscillation

Conclusions

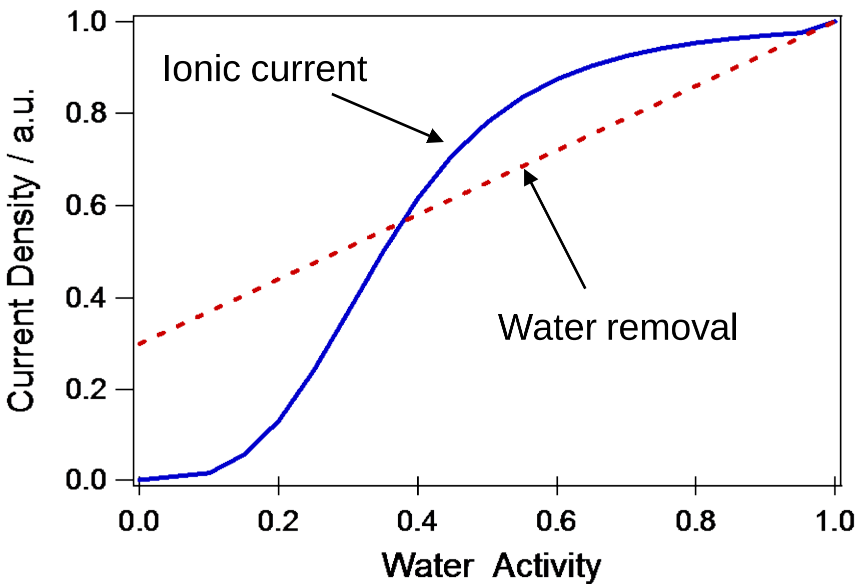
- The driving force for the oscillation are humidity gradients and water transport properties that are nonlinearly interdependent
- Forced convection of water is triggering the „ignition“ transition within the oscillations
- The high operating level provides the “the full scale” performance that a cell could reach if humidity and water transport properties are maximized
- The amplitude of the oscillation is associated to the change of water content of the membrane
- The characteristic transition time in the “ignition” transition depends on the hydrodynamic transport properties of the membrane

Two Operation Points with higher Stability



Benziger et al.(2004)

$$\text{Water removal} = \frac{F_A^{out} P_w^A - F_A^{in} P_{w,in}^A + F_C^{out} P_w^C}{RT}$$



Motivation for using locally resolved diagnostic tools

- Variation of gas concentrations along the flow field as a result of the electrochemical reaction
- The reaction leads to temperature gradients in the cell
- The electrical and chemical potential distribution is based on the local product and reactant concentrations
- The gas composition has a significant influence on the degradation (e.g. corrosion) of the cell